rechargeable?

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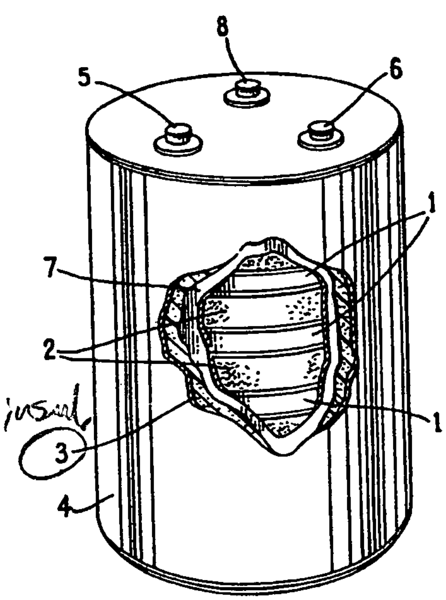

(57) Abstract

A thermal battery incorporating a sacrificial resistive heater (7) connectable between the terminals of the battery and perable to maintain the electrolyte ab ve its freezing point after initiation of the battery and f r as long as useful capacity remains in the battery. The heater may take the f rm of a conducting film deposited on a heat-resisting substrate r a wir coil retained n a f rmer and ~~may be located either within a central shaft of the battery or it may surround the stack of cells within the thermal insulati n layer (3) of the battery.~~ The heater may be directly connected electrically to the ends of the cell stack r it may be connected thereto indirectly via an internal or external timer to be switched on after a pre-determined time lapse from initiation, and the heater may be thermostatically controlled.

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IMPROVEMENTS IN THERMAL BATTERIES

This invention relates to thermal batteries, and is aimed at providing a means capable in many applications of extending the useful life of the battery.

There are two main mechanisms by which the useful life of a thermal battery is terminated - exhaustion of electrical capacity or a rapid rise in its internal resistance caused by cooling below a certain temperature around the freezing point of the electrolyte. For particular battery designs, there is often a considerable imbalance between the life expectancies governed by the separate effects: ideally these should be equal since an excess of cell volume (governing electrical capacity) or thermal insulation represents a cost, size and/or weight penalty. However, due to the usually wide temperature range over which a battery is required to provide a minimum specified performance, its life can often be limited by electrolyte freezing towards the lower end of the temperature range, whilst being capacity-limited at the top end due not only to more extensive side reactions at a higher battery internal temperature but also to a longer time elapse before commencement of electrolyte freezing.

This invention seeks to provide a means by which a small portion of the electrical capacity of a thermal battery can be used, if need be, to supplement the internal resistive heating r counter its natural cooling in order to maintain the electr lyte above its freezing p int.

This invention therefore c nsists of a thermal battery comprising a sacrificial resistive heater connectable between the terminals of the battery and operable to maintain the temperature of the battery electrolyte above its freezing point for as long as useful electrical capacity remains in the battery.

The heater may be arranged to operate as soon as the battery has been initiated or it may be switched on by a timing device, for example after a given interval after initiation of the battery, and in either case it may be controlled by a thermostat. In the latter case, the thermostat would be arranged to cut in when the temperature of the electrolyte was somewhat higher than the freezing point - perhaps by as much as 50°C - since the electrolyte will continue to cool until heat dissipates through the electrolyte at a sufficient rate to compensate for the rate of heat loss.

The heater may be in one of several forms - thus it may be a wire coil enclosed in an electrically-insulating material such as mica and supported around the periphery of the cell stack of the battery inside the battery thermal insulation layers or as a cartridge heater within a central hole in the cell stack, or the heater could be an electrically-conducting heat-resisting film formed or deposited on an insulating substrate at similar locations.

For simplicity the heater could generate heat uniformly over its surface, but it could be designed to generate greater heat in those areas where more heat is lost or where the electrolyte tends to freeze the most rapidly.

By way of example, the invention will now be described with reference to the drawings, of which

Figure 1 is a schematic partly cut-away perspective view of one embodiment of a thermal battery incorporating the invention, and

Figures 2 t 8 are graphs illustrating th effect of sacrificial heaters n the p rf rmance of thermal batteries f

different sizes perated under various conditions.

Referring to Figure 1, a thermal battery consists f stack of cells 1, each consisting of at least an anode, electrolyte and cathode in disc form, and pressed, either individually or in multiples, together with a similar disc 2 of pyrotechnic material between each cell, and mounted around a central hollow shaft (not shown) to provide space for ignition means.

The cells and pellets are contained inside a layer of thermal insulation 3 within a can 4. External terminals of the battery 5 and 6 on the upper face of the battery are connected to interior terminals at the top and bottom ends of the stack of cells respectively.

Located adjacent to the inner face of the insulation layer 3 and in thermal contact with the stack of cells is a cylindrical heater 7 comprising a thin insulating substrate on the inner face of which is formed a heating element consisting of an electrically-conductive heat-resistant film, the film being electrically insulated from the cell stack by a mica layer (not shown) and in electrical contact at its bottom end with the lower interior terminal of the stack of cells and at its upper end with a third external terminal 8. The pattern and/or thickness of the heating element is adapted to provide the necessary electrical resistance to generate the power required for the particular application.

In operation, the battery is initiated by firing the pyrotechnic material 2 raising the temperature of the electrolyte above its melting point, which in the typical case of a LiCl/KCl electrolyte is 352°C. On melting, the electrolyte becomes conductive and enables the cells to supply a useful current. In the absence of any heater, the electrolyte will steadily cool down at a rate dependent on the amount of insulation provided and the heat generated by current flow, a functi n of the external load, through the cell stack.

Under s me conditi ns, the electr lyte will begin t

freeze just as the electrical capacity of the battery has exhausted, but in other conditions the electrolyte will freeze before this stage is reached. As an alternative to providing greater insulation – to which there is in any case a practical limit – to utilise fully the capacity of the battery the terminals 5 and 8 are interconnected by an external timing unit, and when the circuit is closed some time after initiation of the battery the heater operates, reducing slightly the output available between terminals 5 and 6 but extending the time elapse before the electrolyte freezes.

In other embodiments of the invention, the upper end of the heating element is connected internally with the upper interior terminal of the cell stack, either via an integral timer or directly so that the heater operates immediately the battery is initiated. In any embodiment a thermostatic element may be incorporated into the connections and in thermal contact with the electrolyte so that the heater only operates when the temperature of the electrolyte approaches its freezing point.

The effect on the battery output of the incorporation of a heater of the kind described can be seen from the results, reproduced in Figures 2 to 8, of computer simulations of various heater dissipations (expressed as various electrical resistance values) incorporated in large, medium and small sizes of commercially available batteries, and at high and low ambient temperatures.

In Figure 2 output voltage/time curves have been plotted for a battery of medium size at an ambient temperature of -40°C, having no heater and with heaters of 10Ω, 20Ω, 50Ω and 100Ω (the lowest resistance heaters dissipating the most power) and connected to the same external load.

With no heater, the output from the battery declines only very slowly until about 900s from initiation: the firing of the pyrotechnic will have raised the electrolyte temperature to well above its fr ezing p int but by 900s re-freezing starts to take place. The electrolyte steadily freezes thereafter

causing a rapid fall in battery output to an unacceptable level after a total time elapse of 1200s or so.

The effect of a 100Ω heater switched on after about 300s from battery initiation is seen to prolong an essentially constant battery output at least until about 1500s, by which time the electrical capacity of the battery may be close to exhaustion. The effect of even a 100Ω heater has therefore been sufficient in this case to maintain the electrolyte above its freezing point and therefore in a fully conducting condition. Little further benefit can be gained from the use of more powerful heaters, as the other curves show: a 50Ω heater does not drain the battery significantly but causes a slight reduction in battery output throughout its operation. Use of 20Ω and 10Ω heaters however exhaust the battery prematurely but in certain cases the use of a 20Ω heater would prolong slightly the useful life of the battery - at say 50% of maximum output level.

The above curves assume operation of the battery in an ambient temperature of -40°C. If the same battery is operated at rather higher ambient temperatures then the ignition of the pyrotechnic will raise the electrolyte temperature to a corresponding higher value, so that a longer time will elapse before the electrolyte freezing point is reached. Capacity exhaustion is thus more likely to occur first. This is illustrated by the curves in Figure 3, where no beneficial effect is apparently gained from the use of even a 100Ω heater with the same battery as before but operated at +70°C. The effect on the output is indeed detrimental due to current drain through the heater. The incorporation of a heater in a battery for use at this temperature might however make it possible to employ considerably less insulation, and the resulting curves would then be more akin to those of Figure 2 even at the higher temperature - the use of, say, a 100Ω heater would compensate f r the decr ase of insulati n.

C nsist nt results are found in simulations of larger and

smaller batteries. Figur 4 shows the effect on electr lyt temperature of a larger battery of various heaters switched on at 1100s in order to attempt to maintain output to 2000s, this not being possible without a heater due to electrolyte freezing at 352°C, which is seen to commence at about 1750s. It is seen that a 50Ω heater is sufficient to maintain the electrolyte above freezing, more powerful heaters causing unnecessary current drain and even overheating. The effect of this on output is seen in Figure 5, showing that heavy pulses can be obtained from the battery at high voltage up to 2000s with a 50Ω heater, and the effect of current drain with the other heaters is quite clear.

With a small battery, the effect of heat loss through the insulation is more marked, especially at low temperatures. From Figure 6 it is seen that in spite of greater current drain 20Ω and 10Ω heaters are needed to maintain the electrolyte above freezing at 352°C in an ambient temperature of -40°. The corresponding output curves in Figure 7 confirm that a 20Ω heater is closer to optimum under these conditions, the similar electrolyte temperature maintained by a 10Ω heater being more than offset by its much higher current drain.

With the same battery used at +70°C though, the effects are very different. From Figure 8 it is seen that since the electrolyte does not freeze during its operation, no benefit appears to be gained from the use of a heater in these conditions. To use the same battery over a wide range of ambient temperatures, some kind of thermostatic control is needed.

The above examples illustrate that the degree of heating needed depends on all the variables under which the battery is used - its size, power requirement and ambient temperature range among others. The use of thermostatic control would reduce unnecessary heating and current drain, while the possibility f using less thermal insulation increases the efficiency of the battery in terms f energy per unit weight or

v lume. Overall it is possible t make the effective capacity of the battery to be less dependent on its operating variables.

Nevertheless, there are many instances - for example for some applications of smaller batteries such as that described with reference to Figure 8 - where a sacrificial heater would not only be unnecessary but would be detrimental by adding to the current drain of the battery, but by reference to all the examples described the extent of usefulness of this invention will be understood.

The heater need not be in the form of a conductor formed on a substrate; it may be in the form of a wire coil, enclosed for example in mica and supported on a heat-resistant former and it may be appropriate in some applications for the heater to be located along the central hole of the battery rather than surrounding the electrolyte. Other variations in the form of the invention will be readily apparent to those skilled in the art.

CLAIMS

1. A thermal battery characterised by comprising a sacrificial resistive heater (7) connectable between the terminals of the battery (5, 6) and operable to maintain the temperature of the battery electrolyte above its freezing point for as long as useful electrical capacity remains in the battery.
2. A thermal battery according to Claim 1 in which the heater (7) comprises a layer of electrically-conducting material formed or deposited on an insulating substrate.
3. A thermal battery according to either preceding claim in which the heater is arranged to surround the stack of cells of the battery and in thermal contact therewith.
4. A thermal battery according to Claim 1 or Claim 2 in which the heater is located within an axial hole extending through the stack of cells of the battery.
5. A thermal battery according to any preceding claim including a timing device arranged to actuate the heater after a pre-determined time lapse after initiation of the battery.
6. A thermal battery according to any preceding claim including a thermostatic device to prevent operation of the heater under conditions where the electrolyte is not in danger of freezing within the required life of the battery.
7. A thermal battery according to any of Claims 1 to 4 in which the heater is connected internally and directly between the terminals of the battery so that heat is generated whenever the battery electrolyte is in a conducting state.

FIG.1

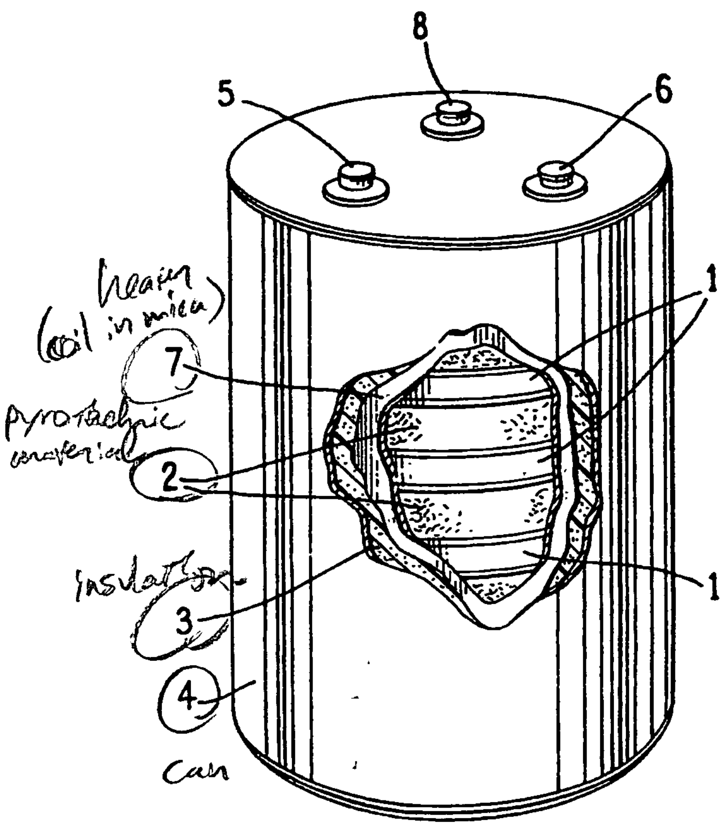

8
5
6
1
heater
(coil in mica)
7
pyrotechnic
material
2
1
insulation
3
4
can

FIG.2

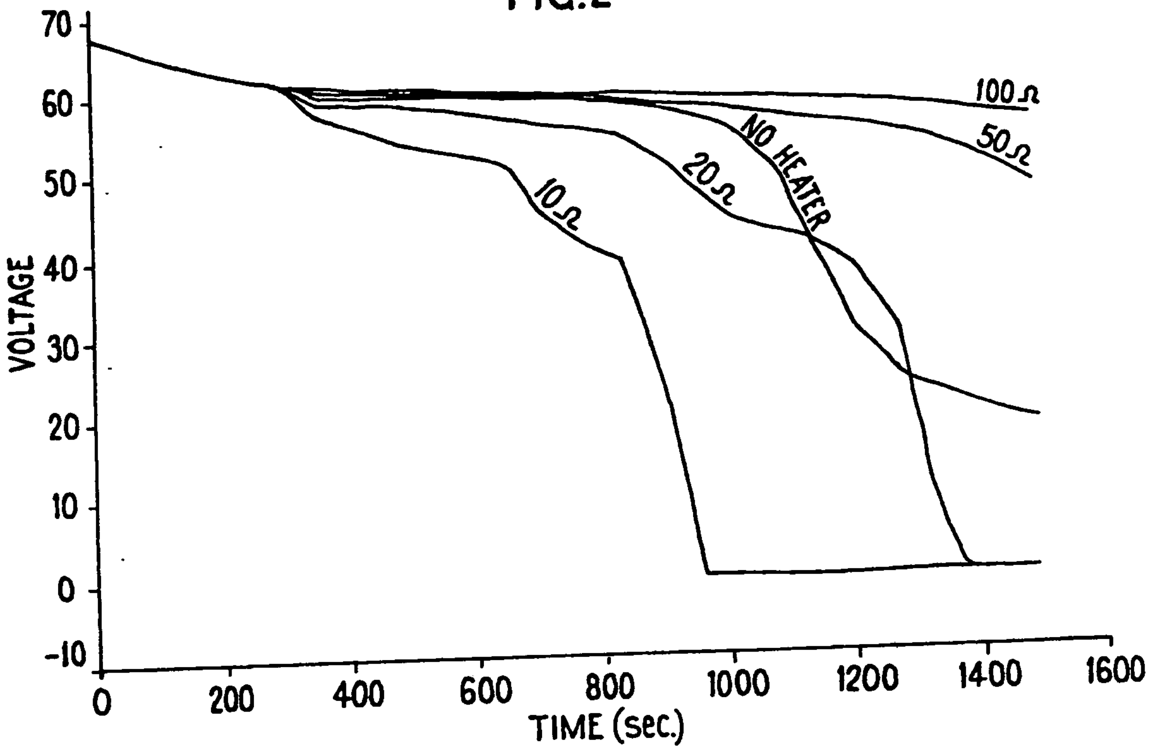

70
60
50
40
30
20
10
0
-10
VOLTAGE
0
200
400
600
800
1000
1200
1400
1600
TIME (sec.)
100 Ω
50 Ω
NO HEATER
20 Ω
10 Ω

FIG.3

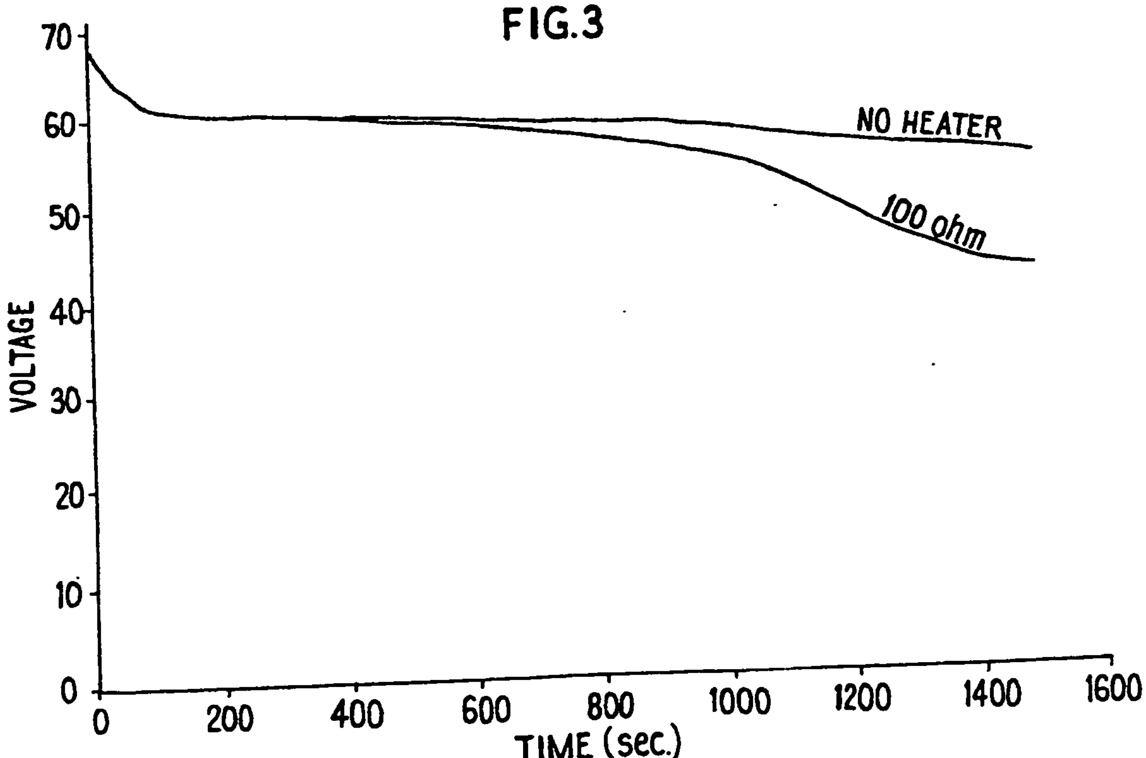

70
60
50
40
30
20
10
0
VOLTAGE
0
200
400
600
800
1000
1200
1400
1600
TIME (sec.)
NO HEATER
100 ohm

FIG.4

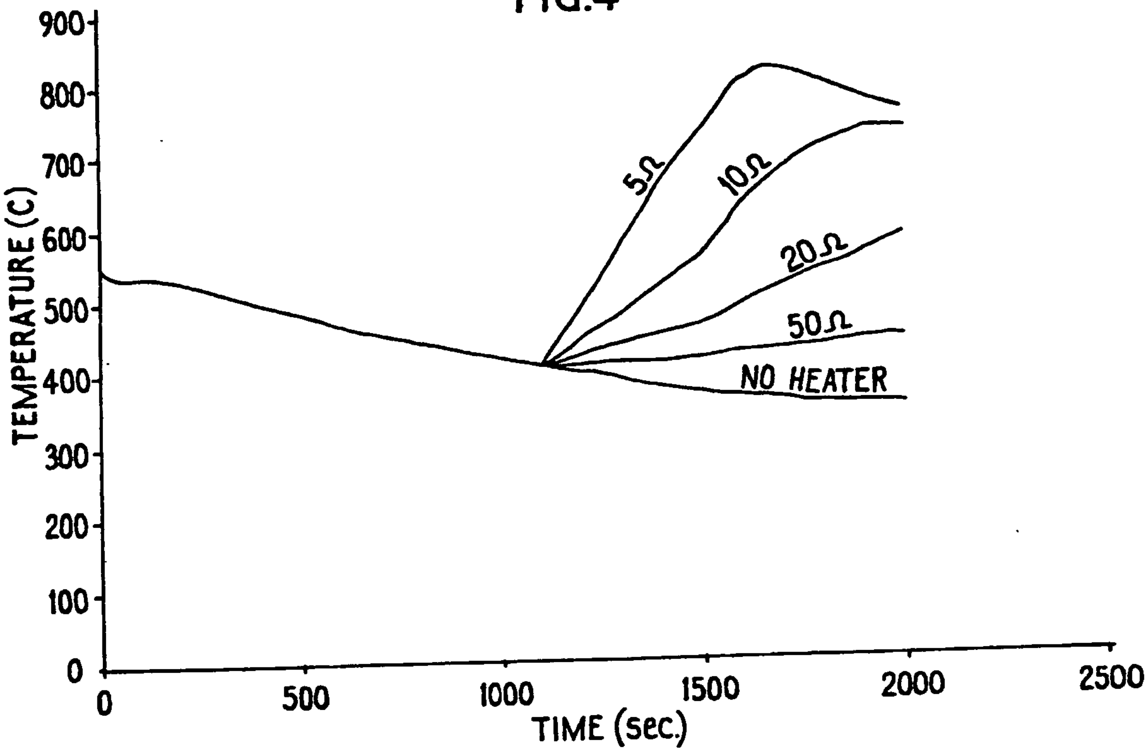

TEMPERATURE (C)
900
800
700
600
500
400
300
200
100
0
5Ω
10Ω
20Ω
50Ω
NO HEATER
0
500
1000
1500
2000
2500
TIME (sec.)

FIG.5

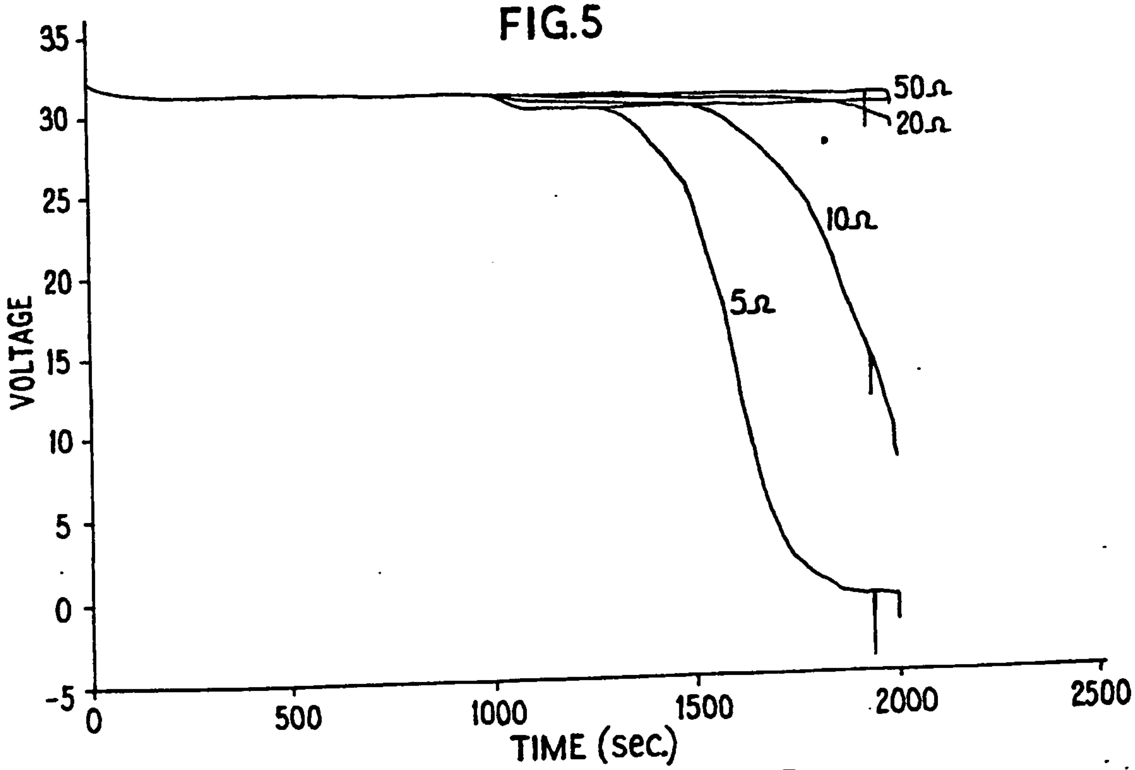

VOLTAGE
35
30
25
20
15
10
5
0
-5
50Ω
20Ω
10Ω
5Ω
0
500
1000
1500
2000
2500
TIME (sec.)

FIG. 6

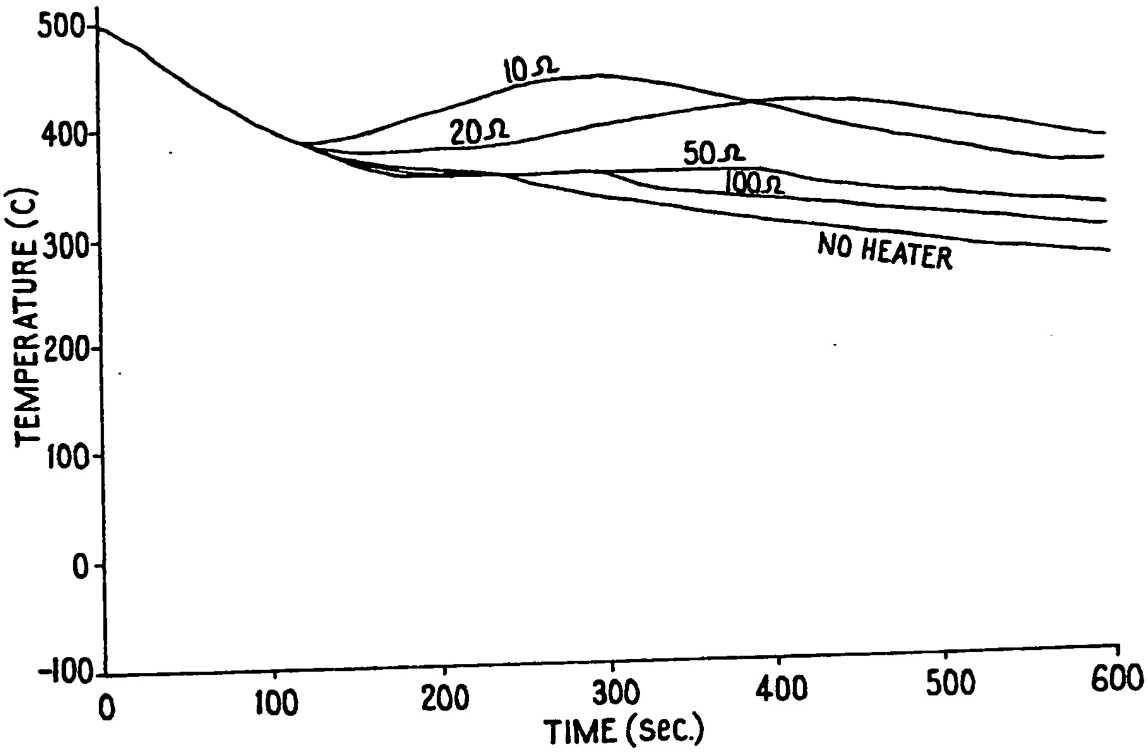

500
400
300
200
100
0
-100
TEMPERATURE (C)
0
100
200
300
400
500
600
TIME (sec.)
10Ω
20Ω
50Ω
100Ω
NO HEATER

FIG. 7

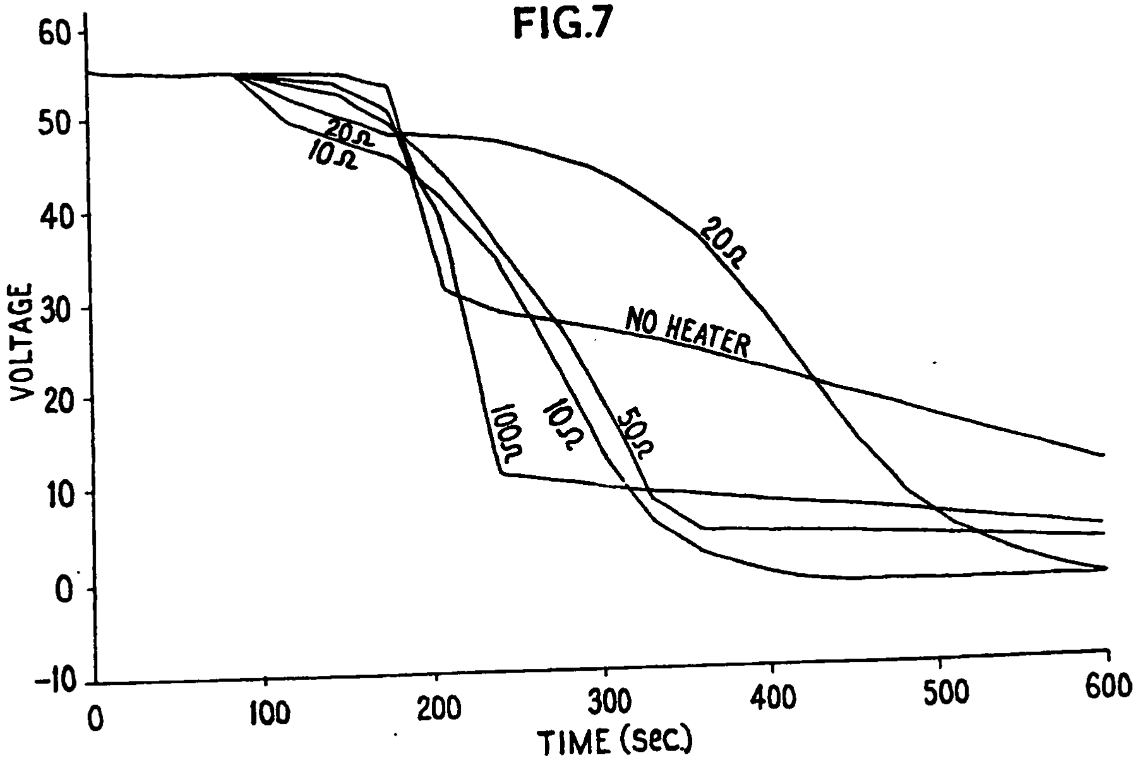
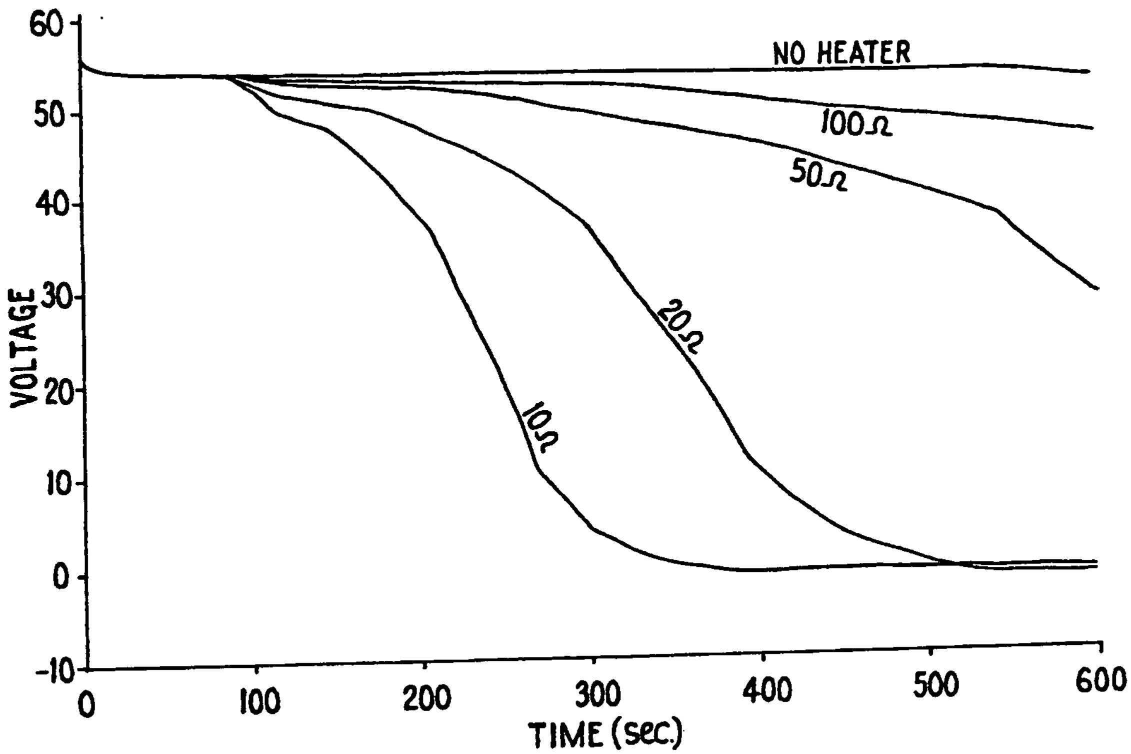

60
50
40
30
20
10
0
-10
VOLTAGE
0
100
200
300
400
500
600
TIME (sec.)
20Ω
10Ω
20Ω
NO HEATER
100Ω
10Ω
50Ω

FIG.8



NO HEATER
100Ω
50Ω
20Ω
10Ω
VOLTAGE
60
50
40
30
20
10
0
-10
0
100
200
300
400
500
600
TIME (sec.)

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 89/00310

I. CLASSIFICATION F SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: H 01 M 10/50

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	H 01 M 10/50, H 01 M 10/39, H 01 M 6/36

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	US, A, 3823037 (ELTON J. CAIRNS et al.) 9 July 1974 see column 3, line 24 - column 4, line 15; column 9, lines 3-63	1,3,6
Y	--	2,4,5,7
Y	US, A, 3649366 (HOWARD J. JORDAN) 14 March 1972 see abstract; column 2, line 52 - column 4, line 3 --	2
Y	DE, A, 3427028 (ECKHARD WAGNER) 23 January 1986 see abstract; page 3, line 31 - page 4, line 8 --	5
Y	GB, A, 2081000 (CHLORIDE SILENT POWER LTD) 10 February 1982 see abstract; page 1, lines 76-87 --	4
Y	DE, A, 3340882 (MESSERSCHMITT-BÖLKOW-BLOHM) 27 June 1985 see the whole document	7

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
29th June 1989	19 JUIL 1989
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	P.C.G. VAN DER PUTTEN

Form PCT/ISA/210 (second sheet) (January 1985)

International Application No. PCT/GB 89/00310

III. DOCUMENTS CONSIDERED T BE RELEVANT (C NTINUED FROM THE EC ND SHEET)

Category*	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
X	GB, A, 2094527 (GEARHART INDUSTRIES INC.) 15 September 1982 see page 3, lines 53-97 --	1
X	US, A, 3775181 (JOSEPH L. RYERSON) 27 November 1973 see abstract; column 3, lines 18-68; column 6, lines 26-32	1,3,6

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 8900310
SA 27711

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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A- 3823037	09-07-74	None		
US-A- 3649366	14-03-72	None		
DE-A- 3427028	23-01-86	None		
GB-A- 2081000	10-02-82	AU-A-	7309281	28-01-82
		EP-A,B	0044753	27-01-82
		JP-A-	57074975	11-05-82
		US-A-	4383013	10-05-83
DE-A- 3340882	27-06-85	None		
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		CA-A-	1124228	25-05-82
		CA-A-	1150716	26-07-83
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		GB-A,B	2096373	13-10-82
		GB-A,B	2094528	15-09-82
		NL-A-	7811317	07-06-79
		US-A-	4351037	21-09-82
		US-A-	4416000	15-11-83
		US-A-	4692911	08-09-87
US-A- 3775181	27-11-73	None		

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